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Micro deep drawing of C1100 conical-cylindrical cups

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Abstract

Micro deep drawing was prompted by the rapid development of micro electro mechanical systems, electron industries, new energy, and biomedical in recent years because of its mass production, high efficiency, high precision, low cost and no pollution. However, most researches concentrated on micro cylindrical cups, few studies were reported on other shaped parts. Micro deep drawing of micro conical-cylindrical cups was investigated in this study by using a micro blanking-deep drawing multiple operation mould. The specimen material was pure copper C1100 with a thickness of 50 μm which was thermally treated in vacuum condition at 723 K for 1 h. Micro deep drawing experiments were carried out at room temperature on a universal testing machine at a drawing velocity of 0.05 mm/s with the lubrication of polyethylene (PE) film. The results showed that micro conical-cylindrical cups with internal conical bottom diameter of only 0.4 mm were well formed. The drawing force and limiting drawing ratio (LDR) micro conical-cylindrical cups were also discussed at the end of this paper.

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Keywords: Micro deep drawing; Micro conical-cylindrical cups; Drawing force; LDR

1. Introduction

With the rapid development of micro-electro-mechanical-system and micro electronics, the demands on micro metallic parts are continuously increased (Geiger et al., 2001). LIGA, micro electric spark, micro machining and laser forming, although can realize bulk production with high accuracy, were limited in efficiency, materials and costs (Vollertsen et al., 2004). Microforming, which produce micro metallic parts or structures with at least two

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dimensions in the sub-millimeter range (Masuzawa, 2000), is prompt in the past decade because of its mass production, high precision, high efficiency, low cost, low duration and no pollution (Zhang and Lei, 2009). Micro deep drawing, which is a basic process of micro forming to forming uncorks, hollow, thin walled micro parts, is being one of the research focuses in microforming (Vollertsen et al., 2010).

Some researches have reported on micro deep drawing. Erhardt et al. (1999) studied micro deep drawing by using a local laser heating method to improve the formability of the drawing blank. Saotome et al. (2001) developed a special experimental apparatus and studied micro deep drawing with very thin sheet steels of 0.05, 0.1, 0.2 and 1mm thickness. Vollertsen et al. (2004) studied the influence of specimen size on micro deep drawing based on similarity theory. Justinger et al. (2005) formed cups with diameters ranging from 8 to 1 mm and investigated the influence of punch velocity, microstructure and scaling factor on cup geometry. Manabe et al. (2008) developed a sequential blanking and drawing setup and fabricated a micro cup with only 0.5 mm in diameter using SUS304 ultra-thin foil. Chen et al. (2009) reported that thickness, grain size and number of grains throughout thickness greatly influenced the limit drawing ratio in micro deep drawing. Behrens et al. (2012) formed a micro cup with 0.75 mm inner diameter and studied the forming limit by using magnetron sputtered Al-Zr foils. Fu et al. (2013) investigated the experimental and simulation of micro blanking and deep drawing compound process using copper sheet and revealed that the simulation of microforming process needs to consider the inhomogeneous deformation of material. Gau et al. (2013) studied micro deep drawing with two ironing stages and successfully formed a micro cup with 3.039 mm in height and 2.218 mm in out diameter by using SUS304 which annealed at 1050 ^{o}C with grain size of 45 μm.

Although micro deep drawing was widely studied, most existing researches concentrated on micro cylindrical cups, few studies were reported on other shaped parts. The purpose of this work is to successfully form micro conical-cylindrical cups with internal conical bottom diameter of 0.4 mm. Furthermore, the drawing force and LDR were also studied in this paper.

2. Experimental setup

2.1. Material

Pure copper C1100 was chosen as testing material in this study. The raw material was strain hardened rolling sheet with a thickness of 50 μm. The specified chemical compositions were (wt.%): Cu≥99.90, Bi≤0.002, Sb≤0.002, Pb≤0.005, As≤0.002, S≤0.005, O≤0.06.

To improve the plasticity of the sheet, the raw materials were annealed at 723 K for 2 h in vacuum condition. Tensile tests were conducted to obtain the true strain-true stress curves of the sheet by using a Zwick/Roell Z050 universal test machine, as shown in Fig. 1.

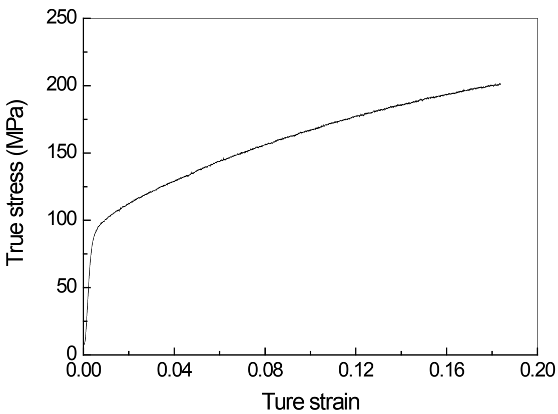

Fig. 1. True strain-true stress curve of 50 μm thick C1100 sheet.

2.2. Mould

Because the diameter of the conical-cylindrical cup to be formed in this study was too small, the localization was quite difficult if a simple operation mould was used. To solve this problem, a blanking-deep drawing multiple operation mould was developed, as shown in Fig. 1. A flat blank was placed onto the die, the upper mould moved downward and a circular workpiece was made. Next, the circular workpiece was pushed into the die cavity by the drawing punch. Meanwhile, an adequate amount of pressure was applied to the blank holder by the spring to form a conical-cylindrical cup after deep drawing.

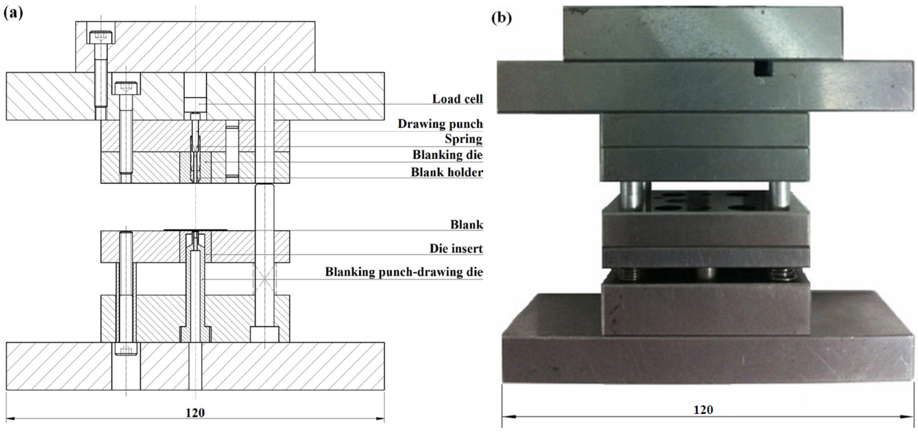

Fig. 2. Micro blanking-deep drawing mould (a) schematic and (b) photograph.

To analyze the micro deep drawing process in details, a very small load cell with a range of 500 N was fixed on the drawing punch to measure the drawing force directly. In order to investigate the drawing ratio in micro deep drawing of micro conical-cylindrical cups, a series of compound punch-dies, blanking dies, die inserts, and blank holders were manufactured in this study.

2.3. Parameters

Micro blanking-deep drawing of conical-cylindrical micro cup experiments were carried out at room temperature on a universal testing machine at a velocity of 0.05 mm/s. The drawing punch stroke and drawing force can be acquired directly by this machine. The diameters of the micro blanking punches were 1.8, 1.9, 2.0, 2.1 and 2.2 mm. The clearance between the micro drawing punch and die was 50 μm, which was equal to the thickness of the workpiece. The radius of the micro deep drawing die was 0.2 mm. The lubricant was PE film, and the blank holder force was 4.2 N.

3. Results and discussion

3.1. Micro conical-cylindrical cups

SEM images of micro conical-cylindrical cups with different drawing ratio can be seen in Fig. 3. It is clear from the figures that the micro conical-cylindrical cups with a maximum drawing ratio of 2.1 were successfully formed except for a few wrinkles in the rim of the cups whose drawing ratio was large. This is because the blank holder force was the same for these micro cups. On one hand, with the increase of the drawing ratio, the degree of deformation increased, which result in the increase of tangential compressive stress and wrinkles. On the other hand, with the increase of the drawing ratio, the width of deformation area increased, which result in the decrease of resistance ability of buckling and wrinkles. There were wrinkles in the micro cups in the existing studies with drawing ratio of 1.8 and 2.0 (Vollertsen et al., 2004; Justinger et al., 2005).

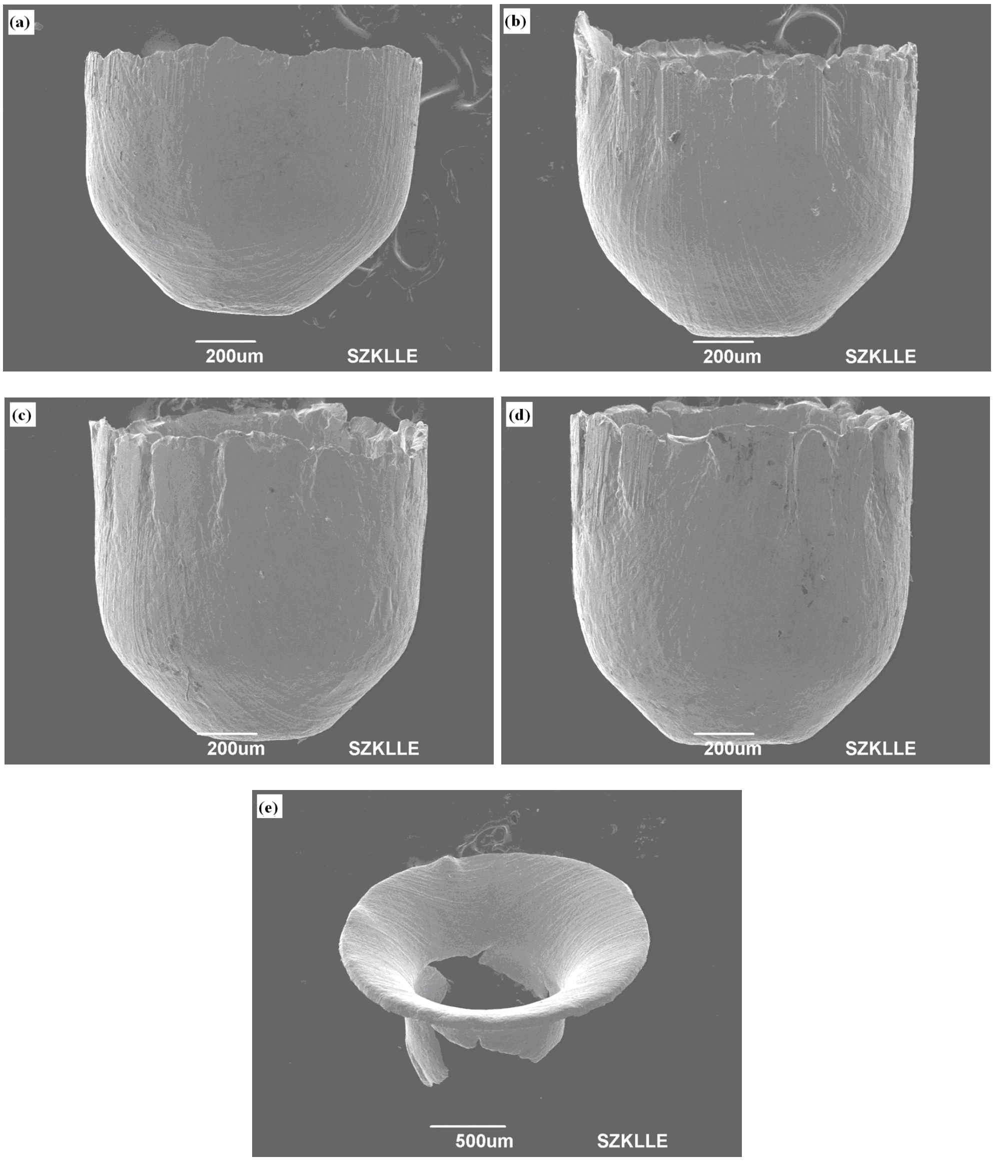

Fig. 3. SEM images of micro conical-cylindrical cups with different drawing ratio (a) K =1.8; (b) K =1.90; (c) K =2.0; (d) K =2.1 and (e) K =2.2

3.2. Deep drawing force

Fig. 4 shows the deep drawing force-deep drawing punch stroke curves with different drawing ratio. It can be seen from the figure that the tendencies of the curves were the same, and there were two peaks in each curve. With the progress of the deep drawing process, the deep drawing force first increased and then decreased and the first peak occurred. The forming of the second peak in the curves because the flange wrinkled due to the lack of sufficient blank holder force and the drawing punch compelled the wrinkled blank drawing into the clearance between the punch and die. With the increasing of the deep drawing ratio, the wall of the micro cup cracked, and the deep drawing process was terminated. The deep drawing force increased with increasing the drawing ratio, and the maximum drawing force increased 12.1% when the drawing ratio increased from 1.8 to 2.1. This is because the deformation degree and deformation resistance of the flange increased with increasing the drawing ratio.

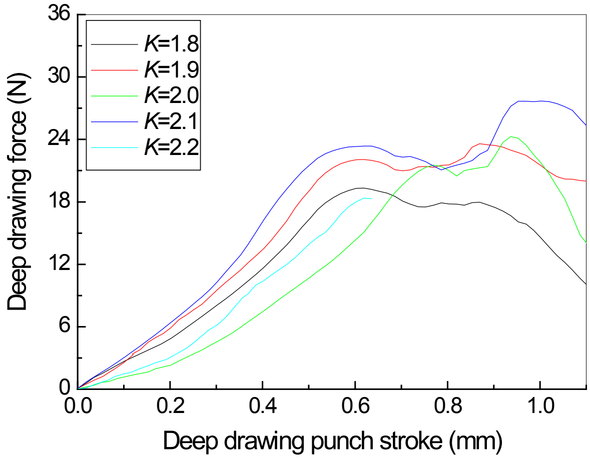

Fig. 4. Deep drawing force-deep drawing punch stroke curves with different drawing ratio.

3.3. LDR

LDR, which is influenced by the mechanical properties of the material, radius of the punch and die, clearance between punch and die, blank holder force, and friction conditions, is quite important in industry in order to making full use of the forming ability of raw material and reducing the cost of manufacture. The drawing ratio K can be computed by the following equation:

$$K = D / d \,, \tag{1}$$

where *D* is the diameter of the drawing blank, *d* is the diameter of the drawing punch. It is clear from Fig. 3 that the LDR was 2.1, which was better than the existing researches (Vollertsen et al., 2004 and Justinger et al., 2005).

4. Conclusions

According to the micro deep drawing experiments with C1100 thin sheet under the lubrication of PE film with a blank holder force of 4.2 N, the following results can be concluded:

1. Micro conical-cylindrical cup with an internal conical bottom diameter of only 0.4 mm was successfully formed by using a micro blanking-deep drawing compound mould.
2. There were two peaks in the deep drawing force-deep drawing punch stroke curves because the lack of blank holder force, and the maximum drawing force increased 12.1% when the drawing ratio increased from 1.8 to 2.1
3. The LDR of the C1100 micro conical-cylindrical cup under the lubrication of PE film with a blank holder force of 4.2 N was 2.1.

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